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Heavy ion detection properties of an indigenous phosphate glass

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Abstract : A phosphate glass indigenously manufactured at the Central Glass and Ceramics Research Institute, Calcutta—a CSIR national laboratory, has been developed as a heavy ion detector. Its physical and chemical etching properties have been measured and studied. Using 70% HNO_3 at 70°C as etchant, it was seen that this phosphate glass was capable of detecting ^{252}Cf spontaneously fissioning fragments and also 200 MeV $^{109}Ag^{15+}$ ions accelerated in NSC Pelletron. The detection properties of this phosphate glass have been studied and the results are discussed.

Keywords : Phosphate glass, etch rates, heavy ion detection

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Motivated by the remarkable properties of the phosphate glass as a detector of light/heavy ions and also due to its increased sensitivity comparable to that of polymers and the fact that these detectors find wide applications in the detection of fission fragments under extreme adverse experimental conditions and radiation background we proposed to develop (under a CSIR project) our own phosphate glass detector of indigenous origin. It was proposed to be used in fusion-fission reaction studies induced by heavy ions in the pelletron energy range. Phosphate glasses have the lowest bond strength amongst oxide glasses and consequently are most sensitive to ionising particles. The etch ratio (*i.e.* the ratio of track etch rate and the bulk etch rate) and the response (*i.e.* the ratio of difference between the track etch rate and the bulk etch rate to the bulk etch rate) are highest for the phosphate glasses and have a very rapidly increasing trend with energy loss (rather stopping power), restricted energy loss and primary ionisation of charged particles [1].

Of the several phosphate glasses that were available, we chose the one designated with the code name PG(Nd) by us. This phosphate glass was developed by the Central Glass and Ceramic Research Institute—a CSIR national laboratory. The chemical composition of this phosphate glass along with some of the physical properties, are listed in Table 1.

Table 1. The chemical composition of our indigenous phosphate glass PG(Nd) and some of its physical properties along with those of some phosphate glasses in common use are listed from literature.

Sl. No.	Chemical composition and some physical properties (Major oxides)	PG(Nd)	VG-13	BP-1	ZnP	PSK-50 or LG-760 (6)
1	P_2O_5	65% wt	65.4% wt	65% wt	78.6% wt	COMPOSITION PROPRITORY
2	BaO	19% wt	23% wt	25% wt	—	
3	K_2O	5% wt	—	—	—	
4	SrO	6% wt	—	—	—	
5	B_2O_3	3% wt	—	—	4.5% wt	
6	Al_2O_3	1 5% wt	—	—	6 7% wt	
7	Nd_2O_3	3.5% wt	—	—	—	
8	Na_2O	—	3.8% wt	5% wt	—	
9	SiO_2	—	—	5% wt	1% wt	
10	ZnO	—	4 6% wt	—	9 2% wt	
11	$Na_2U_2O_7$	—	3.2% wt	—	—	
12	Refractive index	1 5302	1 553	1.543	—	
13	Density (g/cm^3)	2 86	3 06	—	2 69	
14	Softening/transformation temperature (°C)	485	460	—	—	
15	Response $s = V_T/V_B - 1$ (typical)	~ 5 5 (for 200 MeV ^{109}Ag ions) *dE/dx* ~ 46 MeV-cm^2/mg	~ 6 (for 223 GeV U ions)	~ 7 (for low energy Mg ions near Bragg peak)	~ 1 (for 223 GeV U ions)	~ 1 14 to 1 04 (for 223 GeV U ions)

The chemical bulk etch rates with 70% conc. HNO_3 (E Merck) as the etchant along with the detection properties of ^{252}Cf fission fragments are shown in Figure 1. The activation energy is seen to be 0.24 eV.

The nature of the yield distribution curve for ^{252}Cf fission fragments is similar to that in literature [2]. The circular nature of the track diameters reveal the degree of uniformity of the bulk properties of the detector material. The etch ratio, *i.e.* the ratio of track etch rate to bulk etch rate approximately comes out to be ~ 3.5 for the fission fragments.

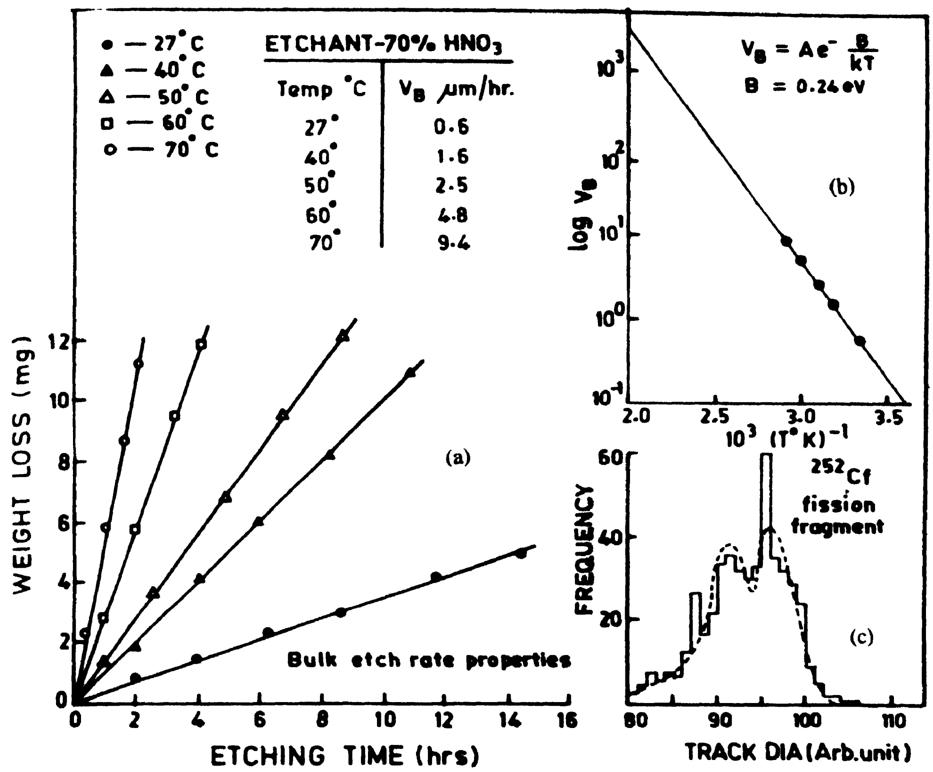

Figure 1. (a) Chemical bulk etch rates of PG(Nd) phosphate glass in 70% HNO_3 at different constant temperatures of 27°C, 40°C, 50°C, 60°C and 70°C, (b) semilog plot of bulk etch rate V_B against inverse of etching temperature in absolute scale $(T°K)^{-1}$ and (c) histogram of the etched fission fragment (^{252}Cf) track diameters

Exposure to 200 MeV $^{109}Ag^{15+}$ ions :

The phosphate glass PG(Nd) detector was also exposed to the 200 MeV $^{109}Ag^{15+}$ beam of the 15 UD Pelletron of Nuclear Science Centre, New Delhi. With 70% HNO_3 at 70 ± 0.5°C as the etchant successive etching technique was employed to find out the etch ratio v and the response s as a function of the residual range R_{res}.

For normal incidence, the etch ratio is given by [1,3]

$$v = V_T/V_B = \{1 + (D/2h)^2\} / \{1 - (D/2h)^2\}$$

and

$$s = v - 1 = (V_T/V_B) - 1,$$

where v = etch ratio, s = response, D = surface diameter of the etch pit, $h = V_B t$ = surface layer of the detector removed by etching; V_B = bulk etch rate, V_T = track etch rate and t = etch time.

$$\text{Residual range } R_{res} = R - (h/2)\left(v/(v+1)\right),$$

where R is the range of the incident ion in the detector material. From the range-energy programmes of Henke and Benton (in ref. [1]), the residual energy corresponding to the residual range, the energy loss and restricted energy loss values are obtained. The results are shown in Figure 2. The curve exhibits an increasing trend of response with residual range since the energy of the incident $^{109}Ag^{15+}$ is below its Bragg peak energy value. The steep response implies a good charge resolution of the detector.

In conclusion, we may say that the detector that we have developed [4] indigenously has a very good response $s = 5.5$ for $^{109}Ag^{15+}$ 200 MeV ions and we intend to use this detector in heavy ion induced reaction studies and fission or fusion experiments which are in an energy domain which is less than that at the Bragg peak.

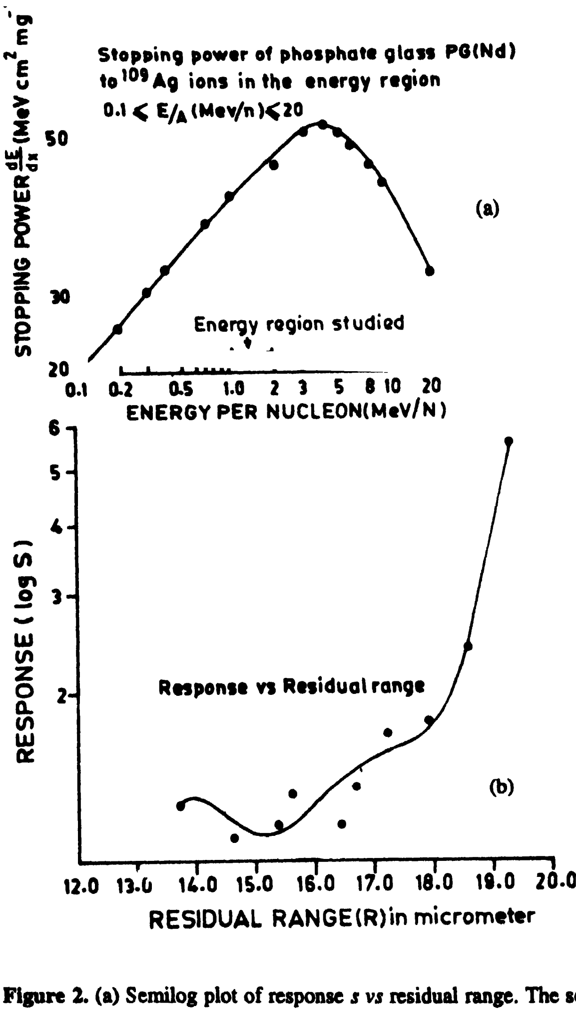

Figure 2. (a) Semilog plot of response s *vs* residual range. The solid line gives the best polynomial fit; (b) stopping power dE/dx *vs* E/A energy per nucleon for ^{109}Ag ions in our phosphate glass PG(Nd) within the energy range $0.1 \leq E/A \leq 20$ MeV/nucl.

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